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Image Quality Performance of CMOS image sensor equipped with Nano Prism

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Abstract

Smartphones with 100 million pixel sensor are on the market. After that, it is expected to mount a higher resolution mobile camera module of 200 million pixel or more. In order to develop high resolution sensor products by mounting more pixels in a limited space, it is necessary to reduce the size of the pixels. There are currently sensors on the market with 0.64um pixels. It is expected that sensors with smaller pixels will be developed in the future. In terms of image quality, the smaller the pixel size, the smaller the amount of light received. Therefore, the image quality deteriorates in terms of noise and crosstalk. To overcome this limitation, various high sensitivity sensors are being developed, and it is advantageous to mount Nano Prism in the development of high sensitivity sensor.

In this paper, we introduce the image quality performance of CMOS image sensor equipped with Nano Prism.

Introduction

From the point of view of image quality, the larger the pixel size of the sensor, the greater the amount of light received, the better the Signal to Noise Ratio, so image quality is advantageous. However, the mobile sensor mounted on the smartphone can provide high resolution in a limited space. Therefore, the pixel size should be small. This concept reduces the amount of light received per pixel, which limits the image quality performance of the sensor. [1] Various attempts have been made to overcome this limitation, and one of them is the sensor equipped with the Nano Prism.

The Nano Prism is define as the Nano photonic micro lens array. The Nano Prism mounted sensor has a prism mounted on the micro lens mounting position of the conventional sensor as shown Figure 1. [2][3]

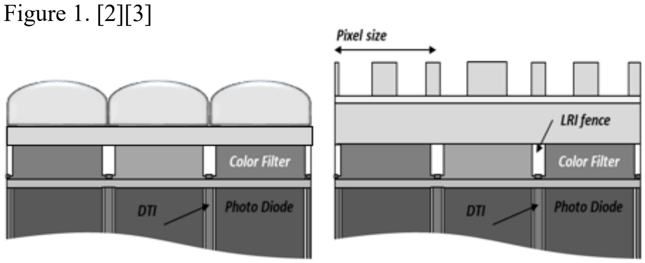

Figure 1. (a) Conventional Sensor, (b) Nano Prism Sensor

Unlike conventional sensor, the sensor equipped with the Nano Prism sensor can draw light from adjacent pixels corresponding to each color channel by using the prism as shown Figure3 and 4. As a result, this does not increase the sensitivity of the pixel, but it achieves the same result as increasing the sensitivity by increasing the amount of light. However, since the signal of the adjacent pixel is not the original signal, it is considered that there will be a negative effect on the image quality. We verified the image quality performance of Nano Prism sensor. Also compare the image quality performance with conventional RGB products.

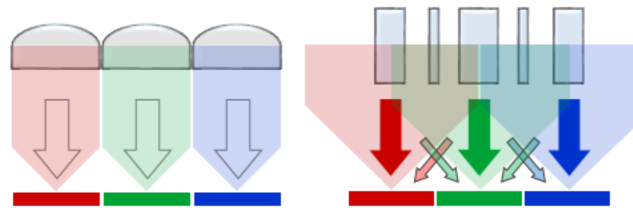

Figure 2. Incident light (a) Conventional Sensor (b) Nano Prism Sensor

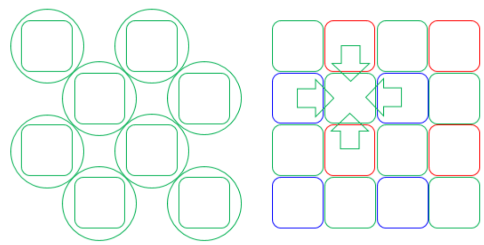

Figure 3 light intensity of Nano Prism Sensor (G Channel)

Proposed approach

The larger the amount of light received per pixel, the more advantageous the image sensor is in terms of noise, which eventually leads to improved image quality. From the perspective of replacing current technology, it is assumed that the image quality is at least equivalent, and a comparison of image quality with the conventional sensor is necessary. To evaluate the image quality performance of the image sensor equipped with the Nano Prism, two cases are considered.

Resolution when matching Signal to Noise Ratio

Resolution and Signal to Noise Ratio are inversely proportional. If one is good, it is difficult to judge whether the image quality is superior. Therefore, if the noise level is set to the same level using the noise reduction function and the resolution is compared, the benefit in image quality can be found.

General image Quality

For products with new technology, it is very important to ensure typical image quality performance. Since Nano Prism sensor has superior sensitivity compared to conventional RGB sensor, so Signal to Noise Ratio superior in terms of image quality. However, since it is equipped with Nano Prism, there may be side effects related to it. We check if there is any degradation in image quality compared to the conventional RGB sensor.

How to Evaluation Method

To evaluate the image quality of the Nano Prism sensor, the 1.12um pixel, 10 mega pixel CMOS image sensor module with Nano Prism was prepared. Then prepare the conventional RGB sensor module under same condition. This is real sensor. Prepare the test jig board that can be combined with the module to obtain raw data as shown Figure 4. Define capture condition, including light source and target. [4]

Figure 4. Set, (a) Conventional Sensor, (b) Nano Prism Sensor

In order to check the Nano Prism proper resolution, the noise reduction intensity of conventional RGB sensor raw is divided into 13 equal parts. Apply the strength step by step and proceed with Application Processor simulation. Secure conventional RGB image with Signal to Noise Ratio level equal to Nano Prism image and check resolution as shown Figure 5.

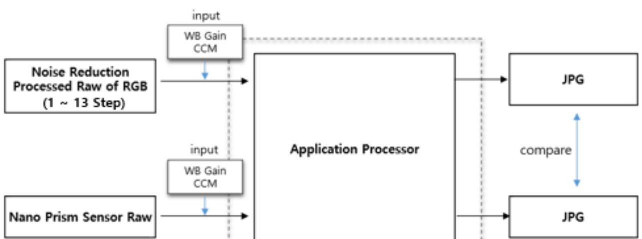

Figure 5. Application Processor Simulation Process for JPG

Result

In the case of when matching Signal to Noise Ratio, the Table 1 calculates the Signal to Noise Ratio by applying the intensity of noise reduction step by step to the conventional RGB sensor raw at 20 Lux. This is to calculate the resolution at similar intensity to the Nano Prism sensor. Signal to Noise Ratio of Nano Prism Sensor is 25.98dB. The conventional RGB Sensor is 26.13dB when the noise reduction intensity is in the level 5, the figure are similar (99.4%) as shown Figure 6.

item	Nano Prism Sensor	RGB Sensor, Conventional							
		Absolute value	Noise Reduction Intensity Level 1	Noise Reduction Intensity Level 3	Noise Reduction Intensity Level 5	Noise Reduction Intensity Level 7	Noise Reduction Intensity Level 9	Noise Reduction Intensity Level 11	Noise Reduction Intensity Level 13
Signal to Noise Ratio (dB) (20Lux)	25.98	25.47 (102%)	25.49 (101.9%)	25.8 (100.6%)	26.13 (99.4%)	26.37 (98.5%)	26.64 (97.5%)	27.0 (96.2%)	27.47 (94.5%)

* Normalization Value (%) = Nano Prism Sensor (dB) / RGB Sensor (dB) * 100

Table 1. Signal to Noise Ratio with Noise Reduction Applied

Figure 6. SNR 20 Lux, (a) Conventional RGB Sensor Noise Reduction intensity Level 5 (b) Nano Prism Sensor

At 20 Lux, the resolution of Nano Prism sensor is 1061(LP/PH). When the intensity of Noise Reduction is in the 5^{th} Level, the conventional RGB sensor has a superiority of 5.7% as shown Table 2.

item	Nano Prism Sensor	RGB Sensor, Conventional							
		Absolute value	Noise Reduction Intensity Level 1	Noise Reduction Intensity Level 3	Noise Reduction Intensity Level 5	Noise Reduction Intensity Level 7	Noise Reduction Intensity Level 9	Noise Reduction Intensity Level 11	Noise Reduction Intensity Level 13
Center MTF 10 (LP/PH)	1061	1150(92.3%)	1147(92.5%)	1136(93.4%)	1125(94.3%)	1112(95.4%)	1103(96.2%)	1083(98%)	1056(100.5%)
25 Stars Average MTF 10 (LP/PH)	839	996(84.2%)	991(84.7%)	980(85.6%)	970(86.5%)	957(87.7%)	944(88.9%)	925(90.7%)	897(93.5%)

* Normalization Value (%) = Nano Prism Sensor (LP/PH)/ RGB Sensor (LP/PH) * 100

Table 2. Resolution 20 Lux with Noise Reduction Applied

In addition, the resolution of the Nano Prism at the corner is relatively poorer than that at the corner as shown Figure 7. It can be seen that Nano Prism is subjectively inferior in resolution at 20 Lux as shown Figure 8.

Figure 7. Resolution 20 Lux, (a) Conventional RGB Sensor Noise Reduction intensity level 5, (b) Nano Prism Sensor

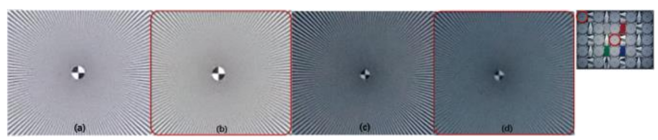

Figure 8. Resolution 20 Lux subjective image, (a) Conventional RGB Sensor Center, (b) Nano Prism Sensor Center (c) Conventional RGB Sensor Corner, (d) Nano Prism Sensor Corner

As a result of the experiment, the following graph as shown Figure 9 and relation expression (1) can be obtain.

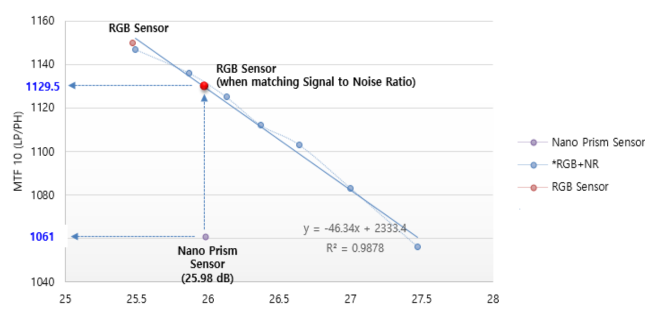

Figure 9. Signal to Noise Ratio and Resolution (MTF10) Relationship

$$Conventional\ Resolution, MTF\ 10(LP/PH)\ at\ 20\ Lux\ = -46.34 \times (Nano\ Prism\ SNR(db)\ \ at\ 20\ Lux) + 2333.4 \qquad (1)$$

In the case of general image quality, at 700 Lux, the Signal to Noise Ratio of the Nano Prism sensor is 36.81dB. The conventional RGB sensor is 36.24dB. At 5 Lux, the Signal to Noise Ratio of the Nano Prism sensor is 22.71dB. The conventional RGB sensor is 20.89dB. As a result, it can be seen that the Nano Prism sensor has an advantage in terms of noise. The difference in noise is more noticeable in low light as shown Figure 8.

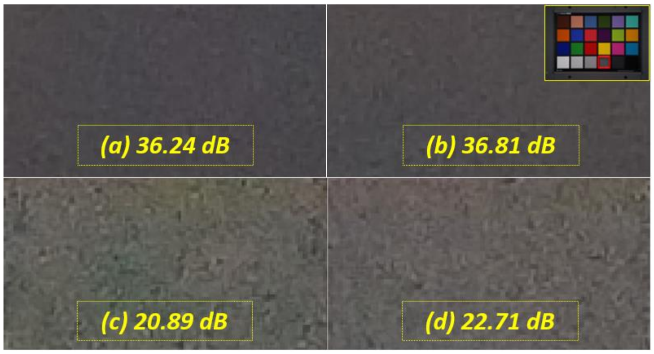

Figure 8. Signal to Noise Ratio, 700 Lux, (a) Conventional RGB Sensor (b) Nano Prism Sensor, Signal to Noise Ratio 5 Lux (c) Conventional RGB Sensor, (d) Nano Prism Sensor

Resolution (25 Stars Average Value, MTF 10) of Nano Prism sensor is 1133 (LP/PH) at 700 Lux. The conventional RGB sensor is 1234. The Nano Prism sensor has an inferiority of 8.2%. As a result, it can be seen that the Conventional RGB sensor has advantage in terms of resolution as shown Table 3 and Figure 9.

item	RGB Sensor, Conventional	Nano Prism Sensor
Center MTF 10 (LP/PH)	1333 (100%)	1294 (97.1%)
25 Stars Average MTF 10 (LP/PH)	1234 (100%)	1133 (91.8%)

* Normalization Value (%) = Nano Prism Sensor (LP/PH)/ RGB Sensor (LP/PH) * 100

Table 3. Resolution 700 Lux

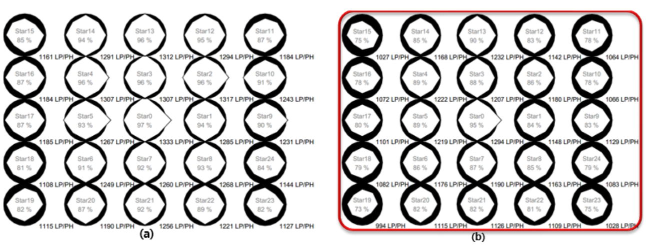

Figure 9. Resolution 700 Lux, (a) Conventional RGB Sensor, (b) Nano Prism Sensor

The Resolution of the Nano Prism sensor is inferior to the Conventional RGB sensor even when viewed subjectively at 700 Lux, as shown Figure 10

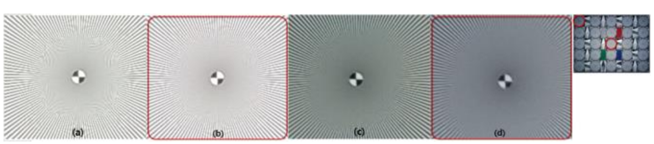

Figure 10. Resolution 700 Lux subjective image, (a) Conventional RGB Sensor Center, (b) Nano Prism Sensor Center (c) Conventional RGB Sensor Corner, (d) Nano Prism Sensor Corner

The texture low and high contrast of the Nano Prism sensor are inferior to the Conventional RGB sensor even when viewed subjectively at indoor, as shown Figure 11 and 12.

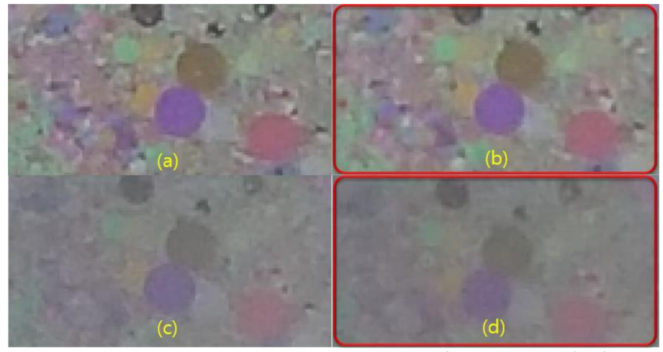

Figure 11. Texture subjective image, Indoor (a) Conventional RGB Sensor High Contrast, (b) Nano Prism Sensor High Contrast (c) Conventional RGB Sensor Low Contrast, (d) Nano Prism Sensor Low Contrast

Figure 12. Texture, Leaf, Indoor (a) Conventional RGB Sensor (b) Nano Prism Sensor

The maze noise of the Nano Prism sensor is inferior to the Conventional RGB sensor even when viewed subjectively at indoor, as shown Figure 13 and 14.

Figure 13. Maze Noise, Rose, Indoor (a) Conventional RGB Sensor (b) Nano Prism Sensor

Figure 14. Maze Noise, Flower, Indoor (a) Conventional RGB Sensor (b) Nano Prism Sensor

High Signal to Noise Ratio characteristics can be obtained by mounting the Nano Prism to the image sensor. Nano Prism sensor is more than 8.7% better than RGB sensor in low light as shown Table 4. However, the quantitative image quality results show that the current level of Nano Prism Sensor is inferior to the conventional RGB sensor in terms of resolution. It means the image quality benefit is small. In addition, cross talk and broken line image quality need to be further improved. We will improve these issue through design optimization and process improvement.

* Regression Analysis

			Normalization Value	Absolute Value		
1. Resolution when matching Signal to Noise Ratio			Nano Prism Sensor	RGB Sensor Noise Reduction Intensity Level 5	Nano Prism Sensor	
Signal to Noise Ratio (20Lux)			99.4%	26.13	25.98	(dB)
Resolution (TE268)	Center Area	MTF 10 (20Lux)	94.3%	1125	1061.00	(LP/PH)
	*Center Area	MTF 10 (20Lux)	**93.9%**	1129.5	1061.00	(LP/PH)
	25 Star Average	MTF 10 (20Lux)	86.5%	970	839.00	(LP/PH)
2. General Image Quality			Nano Prism Sensor	RGB Sensor	Nano Prism Sensor	
Signal to Noise Ratio (700 Lux)			101.6%	36.24	36.81	(dB)
Signal to Noise Ratio (20Lux)			102.0%	25.47	25.98	(dB)
Signal to Noise Ratio (5 Lux)			108.7%	20.89	22.71	(dB)
Resolution (TE268)	Center Area	MTF 10 (700Lux)	97.1%	1333	1294	(LP/PH)
	25 Star Average	MTF 10 (700Lux)	91.8%	1234	1133	(LP/PH)

Table 4. The quantitative image quality result

Conclusion

The quantitative results show that the current level of Nano Prism sensor does not have good overall performance compared to the conventional RGB sensor characteristics. Current level Nano Prism sensor should improve resolution by at least 6.1% while suppressing maze noise artifacts and Signal to Noise Ratio loss.

However, this technology is very important to overcome the limitations of sensor micro pixel technology. If the amount of light received by a pixel can be increased using the Nano Prism, it is equivalent to increasing the sensitivity of the pixel. Also, unlike the micro lens array of the Conventional sensor, it is expected that the amount of light received by each pixel can be controlled.

For example, in the camera module, current technology generates shading and corrects it with Lens Shading Correction. At this time, digital gain is used, and image quality deterioration occurs in the outside as shown Figure 15.

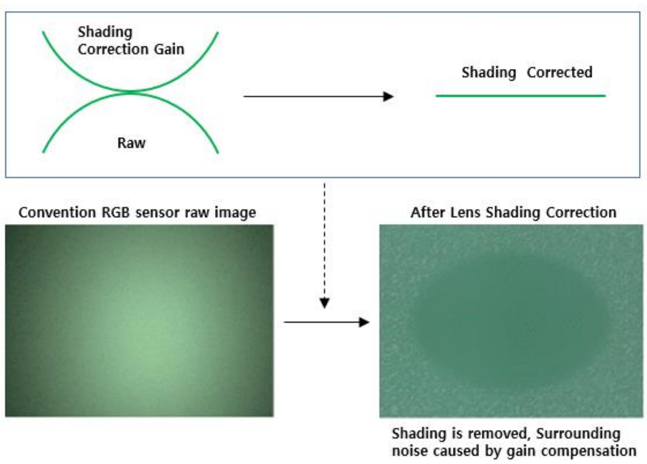

Figure 15. Shading Correction of Conventional RGB Sensor

This issue can take advantage of the characteristics of the Nano Prism to improve image quality degradation due to shading by controlling each pixel to let better light outside than in the center, as shown in Figure 16.

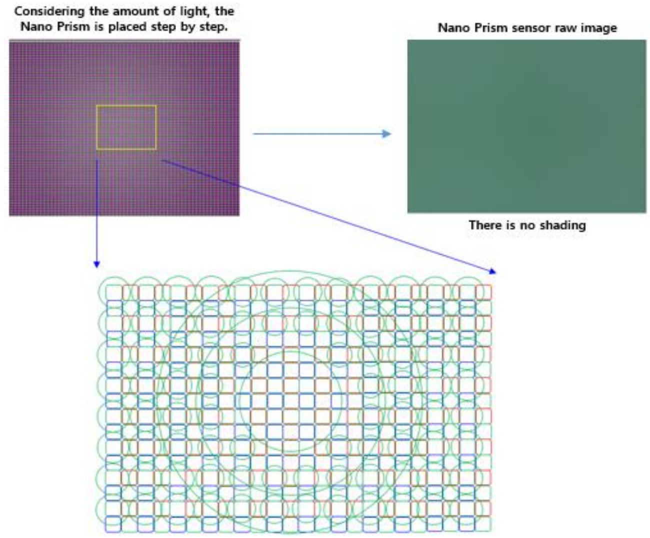

Figure 16. Remove Shading of Nano Prism sensor

In addition, the problems identified in the experiment are equipped with a correction unit in the sensor, and if corrected, an image quality improvement solution can be obtained.

The Nano Prism technology, which feels as if the pixel's sensitivity has been increased, is very important to overcome the limitations of micro pixel technology. We believe that sooner or later the quality will improve and the sensor equipped with Nano Prism will be released to the market. We expect to be able to take the sensor's micro pixel technology to the next level in the near future.

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Author Biography

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